Contrast Discrimination Can Explain Orientation Discrimination

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The Problem

Relative increment contrast discrimination thresholds improve with contrast:
- Weber’s (or Guilford’s) law:
  \[ \Delta C \propto C^{0.7} \]
  \[ \Delta C / C \propto C^{0.3} \]

But orientation discrimination thresholds do not change:
- \[ \Delta \theta \propto C^{-0.1} \approx \text{const.} \]

Typical Model of Early Vision

Stimulus \rightarrow Linear filters \rightarrow Non-linearity \rightarrow Peripheral noise \rightarrow Decision of an ideal observer

\[ \lambda_i \theta \rightarrow R \lambda_i \theta \]
Psychophysical Decision

Discriminate between stimulus A and B by comparing the filter responses:
\[ R^A \text{ and } R^B \]
i.e., thresholds are functions of response differences:
\[ \Delta C \propto f_C(\Delta R) \quad \Delta \theta \propto f_\theta(\Delta R) \]

Hence:
\[ \Delta \theta \propto C^0 \Rightarrow \Delta R \propto C^0 \]
\[ \Delta C \propto C^{0.7} \Rightarrow \Delta R \propto C^{0.7} \]

Consequence for Vision Models

They don’t work!

The Solution?

Discriminate between stimulus A and B by comparing the filter responses:
\[ R^A \text{ and } R^B \]
i.e., thresholds are functions of response differences:
\[ \Delta C \propto f_C(\Delta R) \quad \Delta \theta \propto f_\theta(\Delta R) \]

But:
\[ f_\theta \text{ depends on } C! \]

Slope of orientation tuning curve becomes shallower with C
And the region where $f_\theta$ depends most on $C$ is the most informative.

Fisher Information: $J_{\lambda,\theta} = \left( \frac{\partial R_{\lambda,\theta}}{\partial \theta} \right)^2 / R_{\lambda,\theta}$

Model Simultaneously Fits Contrast and Orientation data

Summary

Improvement in $\Delta C/C$ with $C$ suggests that neuronal responses increase with $C$, but lack of improvement in $\Delta \theta$ suggests they do not.

However, when response is sigmoidal in $C$, effective tuning curves become shallower with $C$.

This reduces Fisher information because it reduces $\partial R / \partial \theta$.

Most affected are the neurons which are most informative about stimulus orientation.

Net effect: contrast-dependent change of tuning counteracts increase in response.